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Gas burners used for combustion of biomass-generated gas and gas-like waste

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Abstract. Original burners used for ecologically safe combustion of natural (soil) gas implement stadial combustion with varying levels of oxygen deficiency in their separate zones created by the flame vortex, which correlates with the capabilities of other effective hardware. Process of NO_x reduction with the use of uncomplete combustion products is organized simultaneously with the use of the new technology of maintaining inner ejection in the flame vortex and zone of intensive mixing while weakening the whole flame vortex's twist. This lets us adapt the designs for combustion of biomass-generated gas and gas-like waste.

1. Introduction

The usage of gas burners for burning natural (soil) gases is very common. Among these gas burners the ones that have cone-shaped outlet canal (a cone with the narrowing on the exit) for compressing the produced flame are less-common. This narrowing is useful for accelerating the air stream in the fuel inlet zone. It strengthens the turbulent mixing at the root of the flame, intensifying the combustion. Yet that can raise the air pressure even with the slight narrowing of the outlet canal. It is possible if the intensity of the flame vortex does not lower due to the loss of the rotational inertia of the stream at the walls of the exit canal. However, narrowing of the outlet canal reduces the diameter of the zone of inner ejection on the axis of the flame vortex and lowers the inflow of the hot gases from the firebox. This leads to the decrease of reliability of the fuel ignition and combustion. Combustion of synthetic gases produced by gasification of biomasses or other gases with low caloric value exacerbates the problem.

2. The analysis of burners' schemes and of possible modes of effective gas combustion

The evidence from practice suggests that gas burners with cone-shaped outlet canals in some cases are very effective in suppressing nitrogen oxide (NO_x) emissions. They can also achieve the minimum concentration of gases with incomplete combustion (CO, H₂) and even of hydrocarbons of the C₂₀H₁₂ group. The best of those gas burners showed the definitive compromise between ecological and efficiency characteristics of the combustion of different fuels. The compromise is based in the thorough understanding of the processes that develop in the flame vortex when creating different levels of oxygen deficiency in separate combustion zones. This demands an adequate insight of the turbulent mass exchange in the intensely twisted streams.

For example, burners of some "Siemens" gas turbines, which have been on the market for a long time, implement a complex scheme that implies consistent technological operations of soil gas combustion with various concentrations of O₂ in the flame. In some cases they showed the lowest possible level of NO_x concentrations outside the turbine (15–16 mg/m³) with the concentration of CO



in the combustion gases no more than 5–10 mg/m³ (this data is evidently relating to the real concentrations of O₂ in the exhaust gas of these turbines. For obvious reasons we do not possess the detailed chart of gas burning technology used in these effective aggregates).

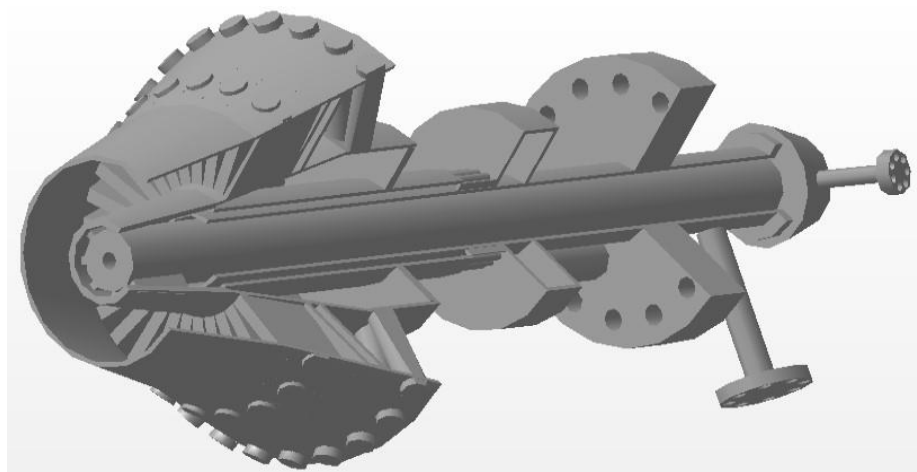


Figure 1. A simplified chart of the ‘Siemens’ gas turbines burner used for efficient and ecologically safe soil gas burning.

The advances of the scheme are supposedly tied to the implementation of consistent flame vortex forming techniques. Fuel burns down as the vortex develops in the different stages with controlled oxygen deficiency and enhanced concentrations of CO and H₂. That control is implemented in the whole volume of the flame vortex. Different levels of oxygen deficiency are maintained in its zones and in the concentration of intermediate products of combustion located in the burners, the cameras outside them and even in the canal between the vanes (in the flow channel) of the early stages of the gas turbine. Although thorough analysis of such scheme is greatly obstructed, we believe that it should not be distilled down to the control of the diffusion and kinetic combustion. It also should not be narrowed down to the basic schemes of two- and three-stage combustion. The most adequate way to look at this gas burning scheme is to consider it as successive stages of combustion with different levels of oxygen deficiency and to complete it with processes developing in the stream of products of combustion in the canals between the vanes of the early stages of the turbine. Large amounts of air produced by cooling of the vanes are inflowing in the gas stream between the vanes.

For obvious reasons we do not possess the data about the expense of the vanes’ cooling airstream and its correlation with the expense of the air that is lead to the different canals of the burner. We suppose that complete combustion of CO and H₂ gases can finish not only in the cameras outside the turbine but also in the canals between the vanes of the early stages of the turbine. A big part in such technology is played by reactions of NO_x reduction into molecular nitrogen (N₂) that develop in the alternating zones of the stream with different stoichiometry, which at first are distinctive for flame vortexes of the burners and then, in the stream, — for the early stages of the turbine. That is where reactions of NO_x reduction complete and combustion of CO and H₂ finishes. The completion of combustion can happen at higher, but not extreme, temperatures, rising thermal efficiency and power of the turbine. In that case the optimal combination of NO_x emission suppression and complete combustion of fuel and intermediate products of combustion can be implemented.

Our hypothesis for additional reduction of NO_x in the flow channel of the turbine correspond with the data provided in the works of prof. P. Roslyakov [1]. This data suggests that fuel combustion minimizes formation of so called “thermal” and “quick” NO_x especially if the process develops just below the stoichiometry. In that case influence that combustion temperature has on formation of NO_x greatly reduces. Complete combustion of CO and H₂ between the vanes of the turbine will happen

simultaneously with additional reduction of NO_x that were formed antecedently and also those NO_x that form in the process of CO and H_2 combustion.

3. Radial Jet Blowing technology

Gas burners with cone-shaped exit canals that have more simplistic schemes (figure 2 (a)) are used in one of the Russian power plants' PK-47 boilers and they show great results. After 1982 some of the burners were remodeled as per the design of the department of Thermal Power Plants of Ural Politechnical Institute (TPP-UPI) with the help of the students. Before that engineers of the MA ORPPN (Managing Authority of the Organization and Rationalization of Power Plants and Networks) installed burners with the cone outlets, which were designed by CBTI (Central Boiler-and-Turbine Institute) with their chessboard manner arrangement on the sides of the combustors. The burners had thermal unit capacity of about 70–73 MW, which should have raised temperature stress and combustion temperature in their long flame vortexes. That in turn was meant to increase emission of NO_x . Exploitation of these burners with chessboard-like arrangement as per the design of CBTI showed opposite results.

These burners were later enhanced with minimal alterations upon the design of TPP-UPI. The design was based on the results of the research of a new and unheard of method of controlling the intensity of flame vortex and the structure of intensely twisted streams (vortexes) [2]. This technology, developed by one of the authors of this article, was called RJB (Radial Jet Blowing). It proved the unique potential of ignition stabilizing and control of fuel combustion in flame vortexes. At the same time a number of burners proved the potential of control of the intensity of flame vortexes. The RJB technology is more reliable and less costly than installation of outlet stream spreader, even slightly twisted. It is not affected by hardware design or twist register of air stream in the burners or stream in the central zone of the streams — at the axis of vortex.

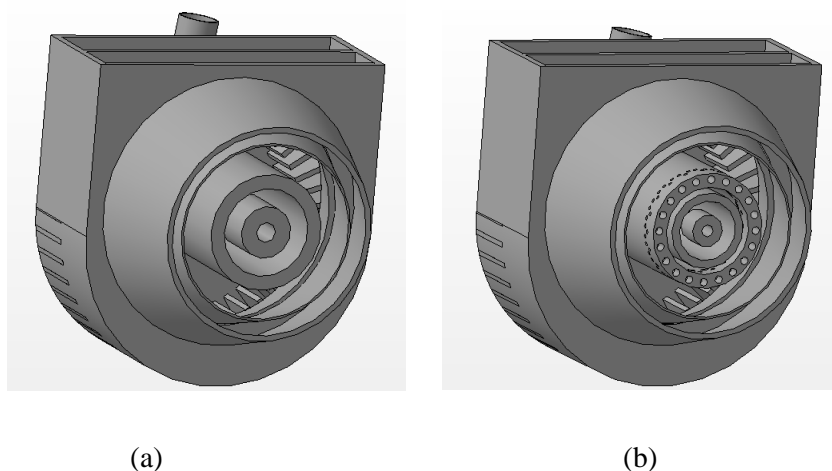


Figure 2. Simplified schemes of the PK-47 boilers' burners, designed by CBTI-ORPPN (a) and by TPP-UPI (b).

In virtue of these redesigned burners (figure 2(b)) after 1983 concentration of NO_x outside the firebox went down to 100–120 mg/m^3 while burning soil gases. Additionally was accomplished its complete combustion. Concentration of CO was lowered to 20–30 mg/m^3 . Concentration of NO_x additionally dropped two to three times when the PK-47 boilers had decreased load. We interpreted the scheme of the burners in the light of prof. P. Roslyakov's works [1] so that it is compliant with comparable schemes, which have been widely used in TPP boilers in Europe for the last 20 years. One of the unique features of these schemes used in the PK-47 boilers as per the design of TPP UPI was creation of reducing atmosphere, that filled almost the entire volume of the firebox with different levels of oxygen deficiency in different zones of the camera. At the same time secondary gas circulation in the camera

and air inflowing through the walls provided complete and soot-free combustion of the reducing atmosphere. The decrease of excess air in combustion products abaft the firebox was record-breaking for Russian energetics at the time. With constant load the oxygen content in the gas pipes, outside the steam superheaters, was no more than 0.3–0.4 percent of total volume. Furthermore, almost complete combustion of gas was implemented provided that the burners were in good condition.

4. Conclusion

We would recommend to use the schemes of the reliable, efficient and environmentally safe burners (figure 2, b) (with some corrections) for burning low calorie gases produced by gasification or ballasted gases — process waste. Exploitability of this adaptation is based on the late works of one of the authors of this article. In these works the author analysed the mechanism of preservation and even strengthening of vortices' near-axial zone twist regardless of any changes (especially descent) of the whole stream. These processes were organised using different approaches to the RJB technology so that intensity and direction of air streams affected the whole flame vortex and partially on its separate zones. The compression of flame vortex by RJB's streams partially imitates the outlet cone of a burner and can weaken the air stream's twist by 5–7 times. Additionally RJB technology can help maintaining the streams' and flame vortices' near-axial zone twist as well as maintaining the intensity of hot gases' ejection along the spinning axis, while sustaining the combustion stability of low calorie suction gases or gas-like waste, ballasted by N_2 , CO_2 or even particulate matter.

The flame vortex axis' zone of its intensive inner ejection can stretch out along the axis when RJB technology is used. The cylindrical domain of the highest turbulence intensity is located on the outer boarder of the ejection zone. By using different schemes of RJB technology we can affect size and intensity of this zone, which is very important in cases of low calorie gases combustion (especially if they are polluted, hot and viscid). It also proves useful for complete combustion of heavy hydrocarbons in found in synthetic unrefined combustible gases. The proposed burners could ease the problem of resins combusting completely alongside the gases in twisted flames in small power facilities with the capacity of 0.2–10 MW. The first attempt of combustion of some gases in prototypes of these burners showed that they are capable of almost complete combustion of hydrocarbons.

It was experimentally proved that it is possible to combust synthetic gases (e.g. suction gas) in long flames at a temperature below 1000 °C or to combust gas-generated resin aerosol particles or their vapor alongside with them without noticeable rise of combustion temperature. This should not result in high rise of NO_x emissions, which is common when combusting suction gases in small fireboxes.

References

- [1] Roslyakov P and Zakirov I 2001 *Nonstoichiometric Combustion of Natural Gas and Fuel Oil Used in Thermal Electric Power Stations* (Moscow: Moscow Energy Institute Press) p 144
- [2] Potapov V 2012 The new method of swirling flows controlling in apparatus with fuel combustion *Electric Power Plants* **10** 28–33